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Influence of Trace Addition of Cd on the Hardness and Impact Properties of 2219 Al Alloy

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Abstract—*Advancement of automobile and aerospace industries has led to growing demand of aluminum alloys exhibiting high specific strength, reasonable ductility, and high fracture toughness. Although influence of alloying on commercial Al alloys is well documented, investigations on the effect of microalloying (< 0.1 wt.%) with elements like Sn, In, Cd, Ag, etc. in wrought heat treatable 2xxx series of Al alloys are very few. 2219 Al alloy and the same alloy microalloyed with 0.06 wt.% Cd were cast and peak ageing time was evaluated. The Vickers's hardness and impact toughness were investigated in homogenized and peak-aged conditions. With trace addition of 0.06 wt. % of Cd, the hardness of 2219 Al alloy increased by 18.6% and 0.2% respectively in homogenized and peak aged conditions. However for both the conditions, the impact toughness decreased due to similar microalloying.*

1. INTRODUCTION

The search for new materials with enhanced properties for industrial and structural applications has led to the development of many metallic alloys. A metallic alloy is a solid solution made of two or more metal elements or metal and non-metal elements in a metallic matrix. Alloys can be a homogeneous solid solution, a heterogeneous mixture of tiny crystals, a true chemical compound, or a mixture of these. Alloys tend to have properties which often happen to be superior to that of their constituent elements. Interest in precipitation strengthened Aluminum Alloys as potential materials for structural use in aircraft and space applications is mainly due to their high strength to weight ratio. The 2xxx series of Al–Cu–Mg alloys of 2124, 2219 and 2618 are extensively being used in aerospace structures demanding good heat resistance properties up to 150°C (Sukumaran *et al*. [14], Wang *et al*. [15] and Yu *et al*. [16]). A clear understanding of the process parameters related to casting, secondary processing and age-hardening heat treatments is necessary for obtaining the required shapes and sizes with desired mechanical properties. These alloys are generally used after deformation processing followed by a sequence of heat treatments. These are wrought alloys, hence are required to be plastically deformed, to reduce the defects (*viz*. segregations, dendrite structures, gas defects, inclusions *etc*.) induced during casting, and subsequently to enhance the mechanical properties. The final strength of the heat treatable aluminum alloys is however decided by the age-hardening process, *i.e*. by a sequence of solutionizing at elevated temperature, quenching to room temperature followed by age-hardening treatment at some particular intermediate temperature. The strength and ductility finally achieved by the alloy depends on the composition, aging time and precipitation temperature of the hardening process. During the solution strengthening heat treatment, copper solute dissolves in the Al matrix which when suddenly cooled forms a supersaturated solid solution of copper in aluminum matrix. During the age hardening treatment, brittle second phase particles precipitate uniformly in the alloy matrix thereby increasing the strength of these materials. In Al–Cu–Mg alloy system, the precipitate formed is generally $CuAl_2$ exhibiting body centered tetragonal (BCT) crystal structure with lattice parameters of a = b = 0.607 nm and c = 0.487 nm and having a micro hardness value (HV) of 400 to 600 kgf/mm^2 [Liu *et al*. [7], Miao *et al*. [9], and Elagin [11]]. The first stage of precipitation reaction is the formation of clusters (GP zones) which are generally mono-atomic layers of Cu on (001) planes of Al lattice. With increase in the ageing time, copper atoms diffuse to the GP zones and form additional layers on to the GP zones. The present research trend to develop increased strength of these materials along with reasonable toughness and low density is by the addition of trace elements (microalloying, i.e. < 0.1 wt.%) like Sn, In, Cd, Ag, *etc*. (Hirosawa *et al*. [4], Sercombe *et al*. [12], Schaffer *et al*. [2], Silcock *et al*. [13], Ocenasek *et al*. [11], Maksimovic *et al*. [8], and Heinz *et al*. [9]) in to the alloy matrix.

In many of the structural applications in aircraft, space or automobiles, materials demand high strength and hardness, along with reasonably good impact strength or toughness properties. The general lack of information in the literature in the above area gives rise to several issues worth investigating. Literature is available regarding the influence of alloying elements like silver, tin, indium, scandium, etc. on the structure and mechanical properties of some commercial aluminum alloys. However, only few literatures are available regarding the effect of trace additions of the alloying elements (microalloying) on the heat treatable aluminum alloys. The present research work is hence aimed at investigating the influence of trace additions of Cd on the hardness and impact properties of 2219 Al-Cu alloy system (having composition of Al-6.3%Cu-0.02%Mg) in as-cast and peak-aged conditions. The alloys containing varying wt. % (0 and 0.06) of Cd were prepared by casting technique. Precipitation hardening behavior of the alloys was investigated by analyzing the peak aging time required to attain the peak hardness value, at a given precipitation temperature. The hardness and impact properties (both notched and un-notched specimens) of these alloys were then investigated in the as-cast homogenized and peak-aged conditions.

2. EXPERIMENTAL PROCEDURE

Rectangular plates of 2219 Al-Cu alloys (Al–6.3%Cu-0.02%Mg) with trace additions of Cd (0 and 0.06 wt. %) were prepared by casting route. The clay-graphite crucible pre-sintered for 3 h at 800°C was used for melting the alloys. Following the common foundry practice, master alloys were first prepared with higher Cu content. This was done to ensure proper control of composition during independent melting and to maintain low alloy melting point. Al–33wt.%Cu master alloy was prepared by melting commercially pure Al with Cu. Required quantity of Al–Cu master alloy was then melted with pure Al ingots to obtain a target composition of Al–6.3%Cu. Once the melt temperature reached 670°C, the dross accumulated at the top of the melt was removed. In the next step we added appropriate amounts of the other elements contained in 2219 Al alloy. This was followed by degassing of the melt to remove dissolved gases by adding 0.2 wt. % of degasser tablets. Mg powder was then added in to the melt and stirred to obtain a uniform target alloy composition. Appropriate amount of Cd grains was then added to the melt. The melt was then stirred gently for a few minutes to ensure uniform mixing of Cd in the melt. The melt temperature was then raised and held at 750ºC (corresponding to 80°C super heat) for 5 min before pouring the same in to the moulds for solidification. The alloys were designated as Alloy-*A* and Alloy-*B* respectively for 0 and 0.06 wt. % of Cd additions.

To ensure a homogeneous composition, it requires the removal of any metastable phases, coring and segregation formed in the as-cast alloys. For this the as-cast alloys were subjected to a homogenizing heat treatment at 510ºC for 10 h. The highest strength for the alloy is obtained by solution strengthening heat treatment followed by precipitation hardening heat treatment. Hence, one set of the alloys prepared in this investigation was given a solutionizing heat treatment at 525ºC for 10 h and subsequently quenched in a water bath to obtain a supersaturated solid solution. Literature showed that the age hardening of most of the 2xxx series Al alloys is carried out at temperatures between 160ºC and 190ºC. Hence the alloys were then age hardened at 170ºC for periods up to 52 h, and hardness were measured at regular intervals. The peak ageing time, *i.e.* the ageing time to achieve the peak hardness, was evaluated as 40 h for both the alloys.

The Vickers's hardness number (*VHN*) of the samples was determined using Vickers hardness testing machine, for both as-cast homogenized and Peak-aged conditions. Hardness specimens were prepared according to the dimension $10\times10\times10$ mm^3 using an Abrasive Cutting Machine. Each hardness value presented is the average obtained from 10 independent indentations under identical loading conditions *viz.* 10 kg load applied for 25 sec using a diamond indenter with 136° included angle. For impact testing of each alloy, two identical samples were machined with dimensions of ~55 mm (length), ~10 mm (width) and ~4 mm (thickness). A notch of ~0.5 mm depth was machined at the center of one of the samples, while the other sample was kept un-notched. The impact strength and toughness of the samples were then evaluated using Charpy test. The hardness and impact properties (both notched and un-notched specimens) of the alloys were thus investigated in as-cast homogenized and Peak-aged conditions.

3. RESULTS AND DISCUSSION

3.1. Vickers Hardness

Table 1 and Table 2 show the Vickers hardness values of the investigated alloys for respectively as-cast homogenized and peak-aged conditions. Firstly it is evident that the hardness of the homogenized alloys was increased by 163.6% and 122.8% due to the peak-ageing heat treatment, respectively for Alloy-*A* and Alloy-*B*. Moreover the hardness of the alloy system increased, with increase in Cd content from 0 to 0.06 wt. %, for both as-cast homogenized and peak-aged conditions. The hardness of the as-cast homogenized alloy increased from 51.7 VHN to 61.3 VHN, with increase in Cd content from 0 to 0.06 wt. %. Similar trend was observed for the peak-aged samples for which the hardness value increased from 136.2 VHN to 136.5 VHN due to microalloying with Cd. It was hence observed that with trace addition of 0.06 wt. % of Cd, the hardness of the 2219 Al alloy increased by 18.6 % and 0.2% in the as-cast homogenized and peak aged conditions respectively.

Table 1: Hardness for as-cast homogenized alloys

Alloy	% Cd	VHN
Alloy-*A*	0	51.7
Alloy-*B*	0.06	61.3

Table 2: Hardness for Peak-aged alloys

Alloy	% Cd	VHN
Alloy-*A*	0	136.2
Alloy-*B*	0.06	136.5

3.2 Impact Toughness

Table 3 and Table 4 show the values of impact toughness (both notched and un-notched) of the investigated alloys respectively in as-cast homogenized and peak-aged conditions. For both the alloys, and for both processing conditions, the impact toughness values of the un-notched specimens were greater than their notched counterparts. Moreover it is also evident that taking the average of notched and un-notched specimens, the impact toughness of the homogenized alloys decreased by 58.3% and 50.9% due to the peak-ageing heat treatment, for Alloy-*A* and Alloy-*B* respectively. For both homogenized and peak-aged conditions, marginal decreases by 16.1% and 1.2% in average impact toughness of the 2219 Al alloy were observed due to microalloying with 0.06 wt. % of Cd. Such decrease in toughness may thus be correlated with the increase in hardness value on the other end. Therefore addition of trace content of 0.06 wt. % of Cd resulted in a considerable increase in hardness, with a marginal decrease in toughness. The strength and ductility are to be additionally conformed from the tensile test results, which are awaiting.

Table 3: Impact Toughness for as-cast homogenized alloys

Alloy	% Cd	Impact Toughness (J/mm^3)		Average
		Notched	**Un-notched**	
Alloy-*A*	0	0.061	0.119	0.090
Alloy-*B*	0.06	0.053	0.098	0.075

Table 4: Impact Toughness for Peak-aged alloys

Alloy	% Cd	Impact Toughness (J/mm^3)		Average
		Notched	**Un-notched**	
Alloy-*A*	0	0.0343	0.0406	0.0375
Alloy-*B*	0.06	0.0340	0.0401	0.0370

4. CONCLUSION

1. The effects of trace additions (0.06 wt. %) of Cd and age-hardening treatment on the hardness and impact properties of cast 2219 Al alloy were investigated.
2. The hardness of the homogenized alloys increased by 163.6% and 122.8%, while the average impact toughness decreased by 58.3% and 50.9%, due to the peak-ageing heat treatment, respectively for Alloy-*A* (2219 Al alloy) and Alloy-*B* (2219 Al alloy microalloyed with 0.06 wt.% Cd).
3. Due to trace addition of 0.06 wt. % of Cd, the hardness of the 2219 Al alloy increased by 18.6% and 0.2% for the as-cast homogenized and peak-aged conditions respectively.
4. Respectively for as-cast homogenized and peak-aged conditions, marginal decrease by 16.1% and 1.2% in average impact toughness of the 2219 Al alloy were observed due to microalloying with 0.06 wt. % of Cd.

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